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A Dynamics Model of Surface Coal Blasting Design Pattern

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Abstract: *The application of dynamic modelling for designing surface coal blasting patterns is presented. By combining the terms of open cast blasting design pattern, production planning, noise, vibration, fly rock, and estimation of drilling and blasting costs, as a decision making tool for planning surface coal blasting efficiency, reducing the environmental impacts of noise, vibrations, and fly rock from the surface coal blasting can be created.*

The results of the model can be used to design surface coal blasting patterns following mine production planning and are based on the theory of the open cast blasting as well. The developed model is incorporated in the assessment of drilling and blasting costs, it also makes it easy to compare the results of the design in terms of the underlying model for the design of the surface coal blasting. Therefore, this model is one of the alternatives that can be used to support the decision making in planning of surface coal blasting design patterns effectively.

Key Words: *Surface coal Blasting Design / System Dynamics Model / Cast Blasting Model*

1. INTRODUCTION

Drilling and blasting for overburden and coal in open cast mines is estimated for 55% of total mining costs in open cast mining, for this reason the planning and design of drilling and blasting to minimize this cost are necessary [1]. The selection of optimum burden, or powder factor, are an importance parameters in open cast blasting design pattern. The interest in this type of blasting is based on a reduced investment in machinery, operation and maintenance, as there is less manipulation of material due to the fact that a large volume of rock, from 40 to 60%, can be projected [2].

Not only blasting design parameters to be decided but environmental impact parameters from blasting also be considered. Thus, the tool that can include both groups of parameter is important.

A dynamics model of surface coal blasting design (DMSCBD) is followed the theory of open cast blasting and is included: the equations and design criteria for surface coal blasting, secondly, environmental control equations for controlling the impacts of noise, vibrations, and fly rock in blasting [3-4], and finally, cost estimation from the drilling and blasting design. This model is created by Vensim Software, which is generally used in system dynamics modelling design [5]. The aim of DMSCBD is to help the designing of optimum patterns, safely charge of explosive per delay, and optimum cost per production.

2. SURFACE COAL BLASTING DESIGN

Cast blasting is being applied with great success in coal mines in South Africa, United States, Australia and Canada [2]. The method may be defined as the use of explosive for the purpose of fragmenting and providing displacement of the overburden to the final spoil pile. The maximum forward displacement is the primary requirement in this blasting method [3].

In case of surface coal blasting design, while using open cast blasting, some methodology or equation was presented. In 1980, D' Appolonia Consulting Engineers of Pittsburgh developed a set of nomographs for designing blasting rounds and mines. Blasting data from actual blasting practices in approximately 100 surface coal mining operations were collected to develop these nomographs. The nomographs are shown in Figs. 1, 2, 3 and 4 [1-2]. Paul et al. (1987) [1] developed a computer aided blasting-round design in an arctic coal mine using the nomographs. It was developed in Fortran 77.

The nomographs contain 3 sets of variables: input variables, intermediate variables and output variables. Input variables are: the diameter of the blast hole (D_e), strain energy factor (E), bench height (H), desired distance the blasted material is to be thrown (R), and density of explosive (P). The intermediate variables are

those which are calculated in the process of determining output variables and they consist of 5 constants as C_1, C_2, C_3, K_1 and K_2, blastability factor (E_0), hole loading length (H_1), hole loading density (P_d) and powder factor (Q). The output variables are those which are used for production drilling and blasting design. They include the burden of the blast hole pattern (B, B_1), spacing between the holes (S), stemming length (S_t), and total charge weight per hole (W). The following empirical equations are the basis of the nomographs:

$$Q = 0.0076R + 0.466E - 0.8616 \qquad (1)$$

$$P_d = \frac{\left(D_e^{1.94} \times P^{1.17}\right)}{343.36} \qquad (2)$$

$$C_1 = \frac{27P_d}{Q \times K_2} \qquad (3)$$

$$C_2 = \frac{K_1 \times C_1}{H} \qquad (4)$$

$$C_3 = 3.93C_1 + 1.011C_2^2 - 112 \qquad (5)$$

$$B = 0.4408C_3^{0.5} - 0.385C_2 - 0.087 \qquad (6)$$

$$H_1 = H - K_1B \qquad (7)$$

$$W = H_1P_d \qquad 8)$$

$$B_1 = 1.585W^{0.296}E_0^{0.752} \qquad (9)$$

$$S = K_2B_{opt} \qquad (10)$$

$$S_t = K_1B_{opt} \qquad (11)$$

The optimum burden B_{opt} can be found while $B=B_1$ by varying K_1 and K_2. D' Appolonia uses a rule of thumb which is $K_2 = K_1^3$ to find B_{opt} [2].

The relationship between compressive strength of rock (CS) and strain energy factor (E) is shown in Table 1 [2].

Table 1 The relationship between CS and E [2]

CS (MPa)	21	27	30	49	66	87	108	122
E	2.8	2.9	2.9	3.1	3.3	3.5	3.7	3.9

Other equations for the calculated patterns of surface coal blasting followed a prototype dynamics model of bench blasting design [6].

Nomograph 1

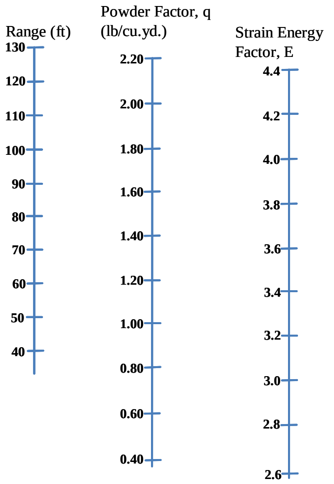


Fig 1 Nomograph 1

Nomograph 2

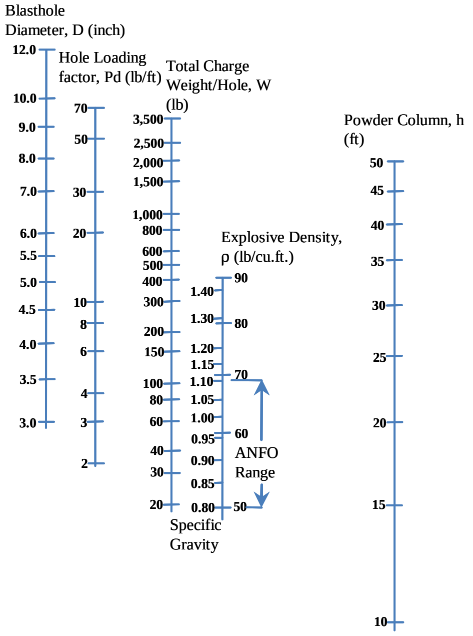


Fig 2 Nomograph 2

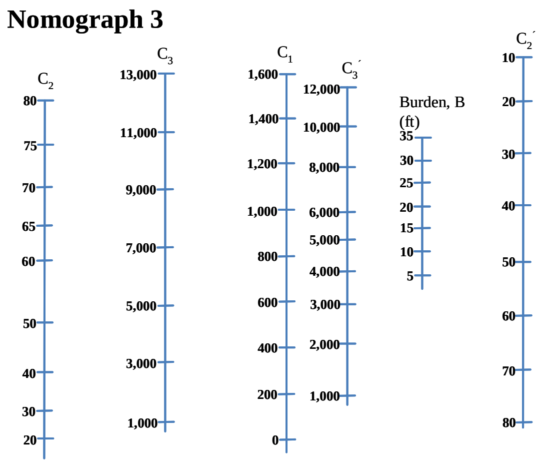


Fig 3 Nomograph 3

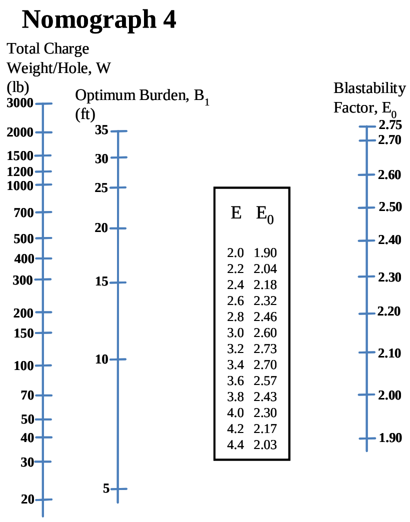


Fig 4 Nomograph 4

3. SYSTEM DYNAMICS

System dynamics is an approach to understanding the behavior of complex systems over time. It is a powerful methodology and computer simulation modeling technique for understanding, and discussing complex issues and problems [7].

System dynamics which founded by Prof. J.W. Forrester in 1950 [8], is a theory of system structure and a set of tools for representing the structure of complex systems and analyzing their dynamic behavior. In Fig 5 shows the generic structures for creating a dynamics model.

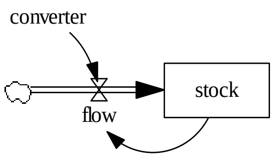


Fig 5 Generic structure of system dynamics model

P. Sontamino and C. Drebenstedt (2012) [6] developed a prototype dynamics model of bench blasting design using Vensim software. The prototype model covered bench blasting design parameters, cost of drilling and blasting parameters and environmental impact parameters. It was an alternative and flexible tool to support user to design bench blasting patterns and decided the suitable condition by terms of economic and environmental control.

4. METHODOLOGY

In this paper, model structures and equations are created in Vensim software [5] following system dynamics theory and open cast blasting design pattern by using the equations converted from the nomographs [1-3]. The model is developed based on the prototype dynamics model of bench blasting design [6]. By changing some parameters and equations from the prototype dynamics model of bench blasting design, the dynamics model of coal blasting design pattern can be determined. The structure of the model is shown in Fig 7.

The simple flowchart of DMSCBD is presented in Fig 6.

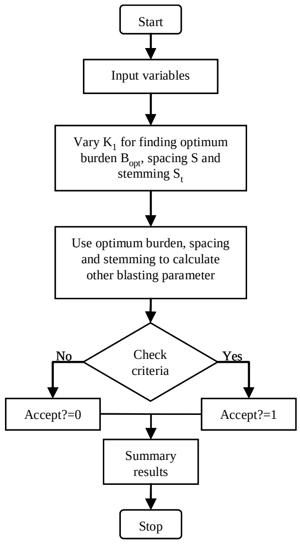


Fig. 6 Simple flow chart of DMSCBD

5. LIST OF VARIABLES

There are 30 main input variables, 34 main output variables, and 4 main criterion variables in Table 4, 5 and 6 respectively. However, in the structure of the model, it is necessary to add more variables than are shown in the table below, such as function for selecting values of coefficient factors in the equations, the converter variables for correcting unit of variables, etc.

Every variable is defined as a symbol in a short description which will be used in the model structure.

Table 4 List of main input variables in DMSCBD

Name	Symbol	Value	Ref.
1. A value of ground vibration equation	A	0.607 (Sandstone)	[4]
2. Alpha value of ground vibration equation	Alpha	1.47×10^{-5} (Sandstone)	[4]
3. B value of ground vibration equation	B	1.463 (Sandstone)	[4]
4. Blast hole inclination (degree)	BHI	0 (Vertical)	*
5. Blasting production planning (tons/day)	BPP	3,200-27,200	Sc
6. Cap per hole (cap/hole)	CH	1	*
7. Compressive strength (Mpa)	CS	1, 5, 10	Sc
8. Hole Diameter (inch)	D	5, 7, 9	Sc
9. Density of ANFO (kg/cu.m.)	DANFO	800 (Loose)	[9]
10. Density of Fuel Oil (kg/Liter)	DFO	0.8	[3]
11. Density of High Explosive (kg/cu.m.)	DHE	1,200 (Emulsion)	[3]
12.Density of materials (kg/cu.m.)	DM	1,600 (Soil)	[3]
13. Input drilling rate (m/min)	ID	0.35	[3]
14. Input bench high (m)	H	9, 11, 13	Sc
15. Bottom charge input (m)	ILf	1	*
16. Subdrilling input (m)	J	0	*
17. K value of ground vibration equation	K	713.23 (Sandstone)	[4]
18. Coefficient of maximum distance of fly rock	Kfr	260	[3]
19. Coefficient of maximum diameter of fly rock	Kfs	0.1	[3]
20. Reference Pressure (bar)	P0	2.0×10^{-10}	[3]
21. Peak particle velocity (mm/s)	PPV	8 (DIN 4150)	[3]
22. Distance between blasting area and measuring area (m)	R	1,500	*
23. Distance to be thrown (m)	Rt	1, 5, 10	Sc
24. Ratio of AN (%)	RAN	94.5	[9]
25. Unit cost per kg of AN (euro/kg)	UAN	0.42	q
26. Unit cost of Cap (euro/cap)	UC	0.62 (Electric)	q
27. Unit cost of drilling (euro/hr)	UD	35	*
28. Unit cost per Liter of Fuel Oil (euro/Liter)	UFO	0.67	q
29. Cost of High Explosive (euro/kg)	UHE	2.29	q
30. Work time for drilling (hr/day)	WTD	8	*

* = Assumption value;
Sc = variables use of simulation in scenarios.
q = in the query

Table 5 List of main output variables in DMSCBD

Name	Symbol	Name	Symbol
1. Cumulative blasting production (tons)	CBPP	2. Optimum burden (m)	B-opt
3. Optimum spacing (m)	S-opt	4. Optimum stemming (m)	St-opt
5. Charge Zone (m)	CZ	6. Blast hole length (m)	l
7. Breakage volume per hole (cu.m.)	VR	8. Breakage weight per hole (tons)	BWH

Name	Symbol	Name	Symbol
9. Weight of ANFO (kg)	Qc	10. Total Weight of Explosive (kg)	Qb
11. Weight of High Explosive (kg)	Qf	12. Number of holes to drill (hole/day)	NH
13. Time for drilling (hr/day)	TD	14.Number of drilling machine required	NDM
15. Cost of High Explosive (euro/day)	CHE	16. Cost of AN (euro)	CAN
17. Cost of ANFO (euro/day)	CANFO	18. Cost of Fuel Oil (euro)	CFO
19. Cost of Caps (euro/day)	CC	20. Total cost of explosive (euro/day)	TCE
21. Total cost of blasting (euro/day)	TCB	22. Total cost of drilling (euro/day)	TCD
23. Total cost of drilling and blasting (euro/day)	TCDB	24. Cumulative cost of drilling and blasting (euro)	CCDB
25. Cost per production (euro/ton)	CPP	26. Q max (kg)	Qm

Name	Symbol	Name	Symbol
27. Maximum hole per delay (hole)	MHpD	28. Maximum distance of Fly Rock (m)	MDFR
29. Noise from Blast (dB)	db	30. Estimate air pressure from the blast (bar)	P
31. Fly rock diameter size (m)	FRD	32. Yield of broken rock (m^3/m)	RA
33. Decision making for all blasting design conditions (1=yes, 0=no)	FDM	34. Real Production (cu.m./day)	RP

Table 6 List of criterion variables in DMSCBD

Name	Symbol	Recommended	Ref.
1. Powder factor (kg/m^3)	PF	0.3-0.8	[2]
2. Vibration problem (1=yes, 0=no)	VP	MHpD>=1	*
3. Noise problem (1=yes, 0=no)	NP	<172 dB	[9]
4. Fly rock problem (1=yes, 0=no)	FP	R>MDFR	*

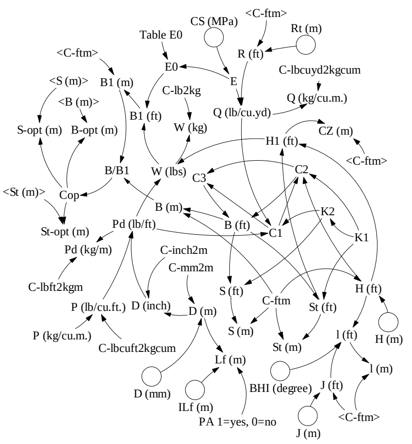
* = Assumption criteria

6. MODELS STRUCTURES

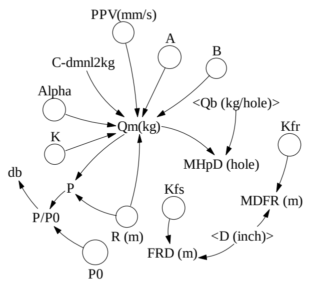
Model structures of DMSCBD are separated into 6 sub-models (Fig 7).

- Blasting Design Patterns
- Blasting Production Planning
- Environmental Control
- Drilling and Blasting Conditions
- Costs of Drilling and Blasting
- Decision Making

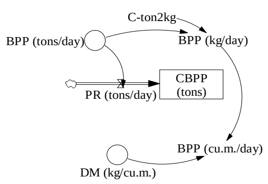
In the model structure, the input variables are shown in ○ symbol, the output and converter variables are shown in normal text, the criterion variables are shown in ⬡ symbol, the cumulative variables are shown in ▭ symbol, the rate variables are shown in symbol, and all of the sub-models are connected by variables with < > symbol.



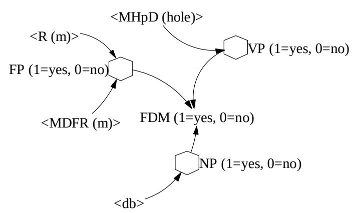
[Sub-model: Blasting Design Patterns]



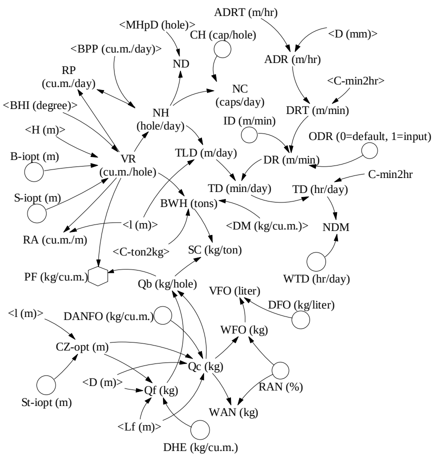
[Sub-model: Environmental Control]



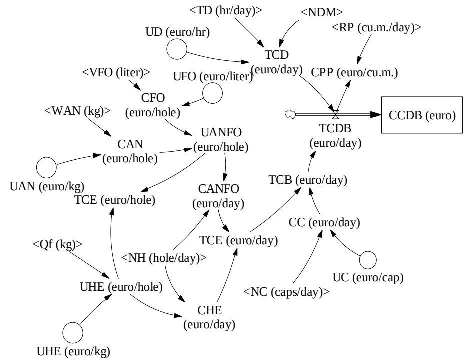
[Sub-model: Blasting Production Planning]



[Sub-model: Decision Making]



[Sub-model: Drilling and Blasting Conditions]



[Sub-model: Cost of Drilling and Blasting]

Fig. 7 Model Structure of DMSCBD

7. MODEL SCENARIOES

From Table 4: List of main input variables in DMSCBD, four variables are taken into account to create sample simulation scenarios, including hole diameter (D), compressive strength of rock (CS), Bench high (H), and the distance to be thrown (Rt). The aim of these sample simulations is to find optimum burden (B-opt), spacing (S-opt) and stemming (St-opt). By changing each variable, there are 81 scenarios to be created following Table 7

Table 7 Metrix variables in the scenario simulations

Variables	Value1	Value2	Value3
1. Distance to be thrown Rt (m)	1 (Rt1)	5 (Rt5)	10 (Rt10)
2. Bench high H (m)	9 (H9)	11 (H11)	13 (H13)

Variables	Value1	Value2	Value3
3. Hole diameter D (inch)	5 (D5)	7 (D7)	9 (D9)
4. Compressive strength CS (MPa)	1 (CS1)	5 (CS5)	10 (CS10)

In each scenario, the symbol is used to make the short explanation, for instance "Rt1H9D5CS10" means: the design condition of the distance to be thrown equals 1 meter, bench high equals 9 meters, hole diameter equals 5 inches, and compressive strength of the material to be blasted equals 10 Mpa.

8. SIMULATION RESULTS

From 81 scenarios, the result of the optimum burden (B-opt), spacing (S-opt), and stemming (St-opt) are determined in Table 8.

Table 8 Optimum burdens, spacings, and stemmings in 81 scenarios

No.	Scenarios	B-opt	S-opt	St-opt	No.	Scenarios	B-opt	S-opt	St-opt	No.	Scenarios	B-opt	S-opt	St-opt
1	Rt1H9D5CS1	3,72	4,82	4,06	28	Rt5H9D5CS1	3,77	3,93	3,82	55	Rt10H9D5CS1	3,82	3,19	3,60
2	Rt1H9D5CS5	3,76	4,58	4,02	29	Rt5H9D5CS5	3,81	3,76	3,79	56	Rt10H9D5CS5	3,86	3,08	3,58
3	Rt1H9D5CS10	3,82	4,30	3,97	30	Rt5H9D5CS10	3,86	3,56	3,76	57	Rt10H9D5CS10	3,91	2,94	3,55
4	Rt1H9D7CS1	4,22	7,20	5,04	31	Rt5H9D7CS1	4,31	5,86	4,77	58	Rt10H9D7CS1	4,38	4,77	4,51
5	Rt1H9D7CS5	4,28	6,83	5,00	32	Rt5H9D7CS5	4,36	5,60	4,74	59	Rt10H9D7CS5	4,43	4,60	4,49
6	Rt1H9D7CS10	4,34	6,41	4,94	33	Rt5H9D7CS10	4,42	5,31	4,70	60	Rt10H9D7CS10	4,49	4,40	4,46
7	Rt1H9D9CS1	4,56	9,69	5,86	34	Rt5H9D9CS1	4,68	7,85	5,56	61	Rt10H9D9CS1	4,79	6,39	5,27
8	Rt1H9D9CS5	4,62	9,18	5,81	35	Rt5H9D9CS5	4,74	7,50	5,52	62	Rt10H9D9CS5	4,85	6,15	5,25
9	Rt1H9D9CS10	4,70	8,60	5,75	36	Rt5H9D9CS10	4,81	7,11	5,48	63	Rt10H9D9CS10	4,92	5,88	5,22
10	Rt1H11D5CS1	4,06	4,91	4,33	37	Rt5H11D5CS1	4,11	3,97	4,06	64	Rt10H11D5CS1	4,15	3,22	3,81
11	Rt1H11D5CS5	4,11	4,65	4,28	38	Rt5H11D5CS5	4,15	3,80	4,03	65	Rt10H11D5CS5	4,20	3,10	3,79
12	Rt1H11D5CS10	4,17	4,36	4,23	39	Rt5H11D5CS10	4,21	3,60	4,00	66	Rt10H11D5CS10	4,25	2,96	3,77
13	Rt1H11D7CS1	4,67	7,32	5,43	40	Rt5H11D7CS1	4,75	5,95	5,12	67	Rt10H11D7CS1	4,82	4,84	4,82
14	Rt1H11D7CS5	4,73	6,94	5,37	41	Rt5H11D7CS5	4,80	5,69	5,08	68	Rt10H11D7CS5	4,87	4,66	4,80
15	Rt1H11D7CS10	4,80	6,51	5,31	42	Rt5H11D7CS10	4,87	5,39	5,04	69	Rt10H11D7CS10	4,93	4,45	4,77
16	Rt1H11D9CS1	5,12	9,87	6,35	43	Rt5H11D9CS1	5,22	7,94	6,01	70	Rt10H11D9CS1	5,32	6,47	5,68
17	Rt1H11D9CS5	5,18	9,26	6,29	44	Rt5H11D9CS5	5,29	7,59	5,97	71	Rt10H11D9CS5	5,38	6,23	5,65
18	Rt1H11D9CS10	5,27	8,68	6,22	45	Rt5H11D9CS10	5,37	7,20	5,92	72	Rt10H11D9CS10	5,46	5,95	5,62
19	Rt1H13D5CS1	4,36	4,94	4,54	46	Rt5H13D5CS1	4,40	3,99	4,26	73	Rt10H13D5CS1	4,44	3,22	3,99
20	Rt1H13D5CS5	4,41	4,67	4,49	47	Rt5H13D5CS5	4,45	3,81	4,22	74	Rt10H13D5CS5	4,49	3,10	3,97
21	Rt1H13D5CS10	4,47	4,38	4,44	48	Rt5H13D5CS10	4,50	3,61	4,18	75	Rt10H13D5CS10	4,54	2,96	3,94
22	Rt1H13D7CS1	5,05	7,40	5,74	49	Rt5H13D7CS1	5,12	6,00	5,40	76	Rt10H13D7CS1	5,18	4,87	5,08
23	Rt1H13D7CS5	5,11	7,00	5,68	50	Rt5H13D7CS5	5,18	5,73	5,36	77	Rt10H13D7CS5	5,24	4,69	5,05
24	Rt1H13D7CS10	5,19	6,57	5,61	51	Rt5H13D7CS10	5,25	5,43	5,31	78	Rt10H13D7CS10	5,13	4,48	5,02
25	Rt1H13D9CS1	5,58	9,88	6,75	52	Rt5H13D9CS1	5,68	8,02	6,37	79	Rt10H13D9CS1	5,77	6,53	6,01
26	Rt1H13D9CS5	5,66	9,35	6,69	53	Rt5H13D9CS5	5,75	7,67	6,33	80	Rt10H13D9CS5	5,84	6,28	5,98
27	Rt1H13D9CS10	5,74	8,77	6,61	54	Rt5H13D9CS10	5,83	7,26	6,27	81	Rt10H13D9CS10	5,91	6,00	5,94

From Table 8, the results of optimum burdens, spacings, and stemmings change following 4 input variables as Rt, H, D, and CS which is shown in summary result (Fig 8).

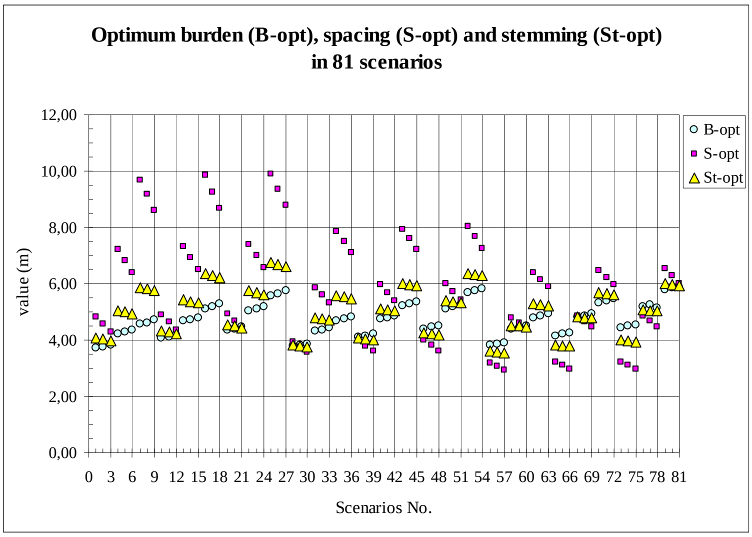


Fig. 8 Summary result of scenarios

In Fig. 8 shows the relationship of variables such as, when increasing the distance to be thrown (Rt), blasting pattern should be reduced. When increasing bench high (H) and/or hole diameter (D), blasting pattern increase, finally when the compressive strength of the material (CS) is increasing, optimum burden also increase but spacing and stemming are decreasing, etc.

9. CONCLUSIONS

A dynamics model of surface coal blasting design shows the results in many scenarios automatically when changed input variables. Thus, It can helps to design surface coal blasting patterns following the theory of open cast blasting design.

However, this model is a generic model. It needs to be developed for more user friendly. An adjustment and update value of input variables related to the site conditions before used are necessary.

In the future, DMSCBD can be extended and included variable in another process of coal mining such as loading, transportation, crushing and processing which will lead to the more useful tool for a decision making in coal mine planning.

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